

## Effect of Gérce alginite on the fertility of an acid sandy soil

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### Introduction

Alginite is an oil shale rock with a high organic matter content, which was formed 3–4 million years ago from fossil (buried and petrified) algae biomass and decayed tufa, at a time when craters (tufa rings, maars) were formed after a period of violent volcanic activity. The water of the upper Pannonian inland sea then leaked into the basin of the craters. Green algae (*Botryococcus brauni*) and other plants/animals proliferated in the nutrient-rich, low salinity waters of the crater lakes, resulting in eutrophication. Mortified in anaerobic conditions, they accumulated at the bottom of the lake as sapropelic mud (SOLTI, 1999).

The name “alginite” indicates its algal biomass origin. Sixty-four elements were identified from alginite rock, most of them located in the inorganic bonds of triple-layered silicates and in the organic or chelate bonds of humus materials. Clay minerals (smectite, illite), carbonates (calcite, dolomite) and amorphous quartz and silica are the dominant mineral components, while gypsum, plagioclase, K-feldspar, siderite, goethite, pyrite and magnesite can also be found in smaller amounts. In 1974, within the framework of the mapping research programme of the Geological Institute of Hungary (MÁFI), Gábor Solti explored one-time volcanic craters buried in alginite and basalt bentonite (SOLTI, 1999).

According to present knowledge, alginite can be found exclusively in the Carpathian Basin, in a quantity of approximately 150 million tons. Opencast mining is economical at three locations. The stock of these three mines represents about 90% of the total resources. Only two mines are in operation, the most significant of which is located in Gérce and owns about 80% of the total alginite. According to drillings made in recent years, alginite forms a layer with an average thickness of 40–60 m on the surface of about 200 ha, with 100 million tons of recoverable reserves. The mine currently operates on 16 ha.

The Soil Protection Laboratory of the Hungarian Agricultural Office in Tana-kajd analysed three alginite samples in 2009. The average composition of the samples was as follows: moisture 37%, CaCO<sub>3</sub> 15%, microelements/heavy metals: Pb

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93, Cr 62, Cu 22, Ni 21, Co 20, As 10, Se < 0.5, Cd < 0.2 and Hg < 0.1 mg·kg<sup>-1</sup> dry matter. The Hungarian Agricultural Office licensing authority has granted a licence for commercial use, since the product has no hazardous components, hazardous waste or other hazardous materials above the permitted limit values.

According to the quality criteria described in the licence, alginit is a brown, odourless, moist, soil-like material suitable for use as a soil ameliorant. It contains a maximum of 40% moisture, at least 14% CaCO<sub>3</sub> and organic material, with upper limit concentrations (mg·kg<sup>-1</sup>) of 100 Cu, Cr and Pb, 50 Co and Ni, 10 As, 5 Se, 2 Cd and 1 Hg. It is licensed for use for the amelioration of acid soils and as an additive for growing mediums until 8<sup>th</sup> September 2019 (MSZHK, 2009).

According to analyses carried out by the Department of Soil Science, University of Bonn and LUFA Nord-West, alginit from Gérce contains 52% clay, 42% silt and 6% sand. After the breakdown of carbonates and humus materials, the clay fraction drops to half, i.e. 26%, while the silt fraction rises to 67%. The reduction in the clay content is due to the disappearance of fine-structured lime from the alginit.

1 m<sup>3</sup> alginit is able to retain about 600 kg water, about 400 litres of which remains available for plants. According to X-ray diffraction analysis, clay minerals are represented by 50% smectite, 40% illite, and 10% chlorite/vermiculite. The swelling of smectite improves the water-holding capacity of the rock. The organic matter content may vary from 6–19%. However, the C/N ratio is above 30 and the organic material is stable, with a long half-life. The CaCO<sub>3</sub> content may be as high as 20%, while the CEC has a value of 35 mol·kg<sup>-1</sup>. These properties may be particularly advantageous for ameliorating unstructured acidic sandy soils with poor water and nutrient supplies. According to the alginit data sheet, alginit is heterogeneous, making an accurate determination of its composition and quality impossible (TNR GMBH, 2010).

The effect of Gérce alginit on the properties of an acidic sandy soil and on spinach growing in 6 kg Mitscherlich pots with uniform additional NPKMgS fertilization was studied in Germany. Alginit was mixed with soil in ratios of 0, 10, 15 and 20%. The cation exchange capacity (CEC) of the soil increased to 2, 26, 38, 44 cmol·kg<sup>-1</sup>, respectively, with the doses, so the increment was 10–20-fold. The shoot and root mass of spinach increased by 20–30%. In particular, the mass of fine, long roots became significant. Overall, a more stable soil structure was established, and the water and nutrient use efficiency of the plants became more favourable. The pH of the soil rose and the water storage capacity increased by 7–10%. In leaching tests, considerable quantities of Ca, Mg, K and Ni left the alginit-treated soil with the percolating water, while the amount of P decreased with increasing alginit doses. Unfortunately, the composition and quality characteristics of the alginit were not published by the authors (REX & SCHERER, 2010).

A micro-plot field experiment was set up on raw calcareous sandy soil with uniform NPK fertilization in Egypt in order to study the ameliorative effects of alginit at application rates of 0, 4, 8 and 16 kg·m<sup>-2</sup>, i.e. 0, 40, 80 and 160 t·ha<sup>-1</sup>. The established grass was irrigated every day from May till September. Under similar conditions 8–10 kg·m<sup>-2</sup>, i.e. 80–100 t·ha<sup>-1</sup> finely ground alginit is recommended, mixed with soil to a depth of 10 cm. In response to the treatment, the structure and water-

holding capacity of sandy soil improved. Longer, finer grass roots were formed, which interwove the soil better, thus stimulating the uptake of nutrients and water. The plant-available water content increased from 6% to 10%, while the water storage capacity rose from 120 to 150 m<sup>3</sup>·ha<sup>-1</sup>, an increment of 12–15 mm·ha<sup>-1</sup>. When mixed into the 10 cm layer, the alginite ratio was higher, so the treatment was more efficient than when it was distributed in 20 cm of soil. The finely ground (< 2 mm) fraction of alginite was also more advantageous, according to the author, but again the composition of the alginite was not published (HELAL, 2010).

A comparison of the characteristics of alginite, communal compost from Gödöllő, sandy soil from Nyírlugos and loamy soil from Nagyhörsök is shown in Table 1.

*Table 1*  
Comparison of the characteristics of alginite, communal compost from Gödöllő, sandy soil from Nyírlugos and loamy soil from Nagyhörsök (Institute for Soil Science and Agricultural Chemistry, CAR HAS)

Characteristics	Unit	Alginite	Communal compost	Sandy soil (Nyírlugos)	Loamy soil (Nagyhörsök)
pH(H <sub>2</sub> O)	-	7.0–7.8	7.0–8.0	4.8–5.8	7.8–8.1
pH(KCl)	-	6.9–7.4	6.0–7.0	4.0–4.2	7.5–7.7
Sand	%	10–20	60–65	86–92	15–20
Silt		40–50	20–25	5.0–9.0	55–60
Clay		40–50	10–15	3.0–5.0	20–25
Saturation percentage	%	60–90	-	23–25	38–40
CaCO <sub>3</sub>	%	5–20	5–8	-	3–5
Humus		5–13	30–40	0.5–0.8	2–4
“Total” salt	%	0.2–0.4	0.4–0.6	< 0.02	0.02
Total N		0.1–0.4	1.0–3.0	< 0.05	0.1–0.2
C/N ratio	-	30–180	7–8	-	10–15

Alginite may contain extremely high amounts of clay, which is also indicated by the high K<sub>A</sub> value (saturation). In addition, its CaCO<sub>3</sub> and organic matter content are also outstanding. However, it does not supply N for the plants, since it has an extremely high C/N ratio. Thus, alginite application should be accompanied by additional N supplies, as it may be ineffective without N. The statement that alginite application ensures a complex supply of macro- and microelements in the soil for the development of plants and that it could act as a substitute for fertilizers and compensate the lack of organic manures is thus misleading (BANOS, 1999).

There can be little doubt that the slightly alkaline or neutral pH, the large amounts of Ca and Mg (and in some cases K, S and P), the excellent water storage capacity and the rich content of organic and mineral colloids in alginite make it suitable for improving the quality and fertility of acid, loose-structured, colloid-poor sandy soils. Alginite can also improve the water and nutrient supply characteristics when combined with N fertilizer.

The drought tolerance of the plants may be enhanced. Due to its colloidal structure alginite is able to bind soil contaminants (detoxification), and may hinder their leaching into the groundwater. On acid sandy soils, alginite can be expected to have liming, pH-increasing and colloid-enhancing effects when it is applied in ameliorative doses.

Factors limiting the utilization of alginite:

- It needs to be transported, applied and manipulated in large quantities (10–100 t·ha<sup>-1</sup>)
- Mined, deposited, “ready to sell” alginite has an average moisture content of 20–25%.
- In Hungary it is the soils of the Nyírség and inner Somogy regions that are most in need of amelioration. These are the poorest regions of the country, so the operation will require financial support from the government.
- The Ni content of alginite may reach or even exceed the permitted 50 mg·kg<sup>-1</sup> dry matter (DM) limit value.

This latter fact has no agronomical, physiological or environmental impact, since Ni will not be mobilized and taken up by plants in this calcareous medium.

### Materials and Methods

One of the oldest long-term field experiments in Hungary is in Nyírlugos, in the Nyírség region. It was set up by LÁNG (1963) on acidic sandy brown forest soil with thin interstratified layers of colloid and sesquioxide accumulation, known as “kovárvány”. The effects of five elements were studied in the experiment, with four levels of N, P, K and Ca and three levels of Mg. The fertilizers were applied in the form of Ca-ammonium-nitrate, superphosphate, muriate of potash, ground limestone and dolomite powder. There were 32 treatments with 4 replications, giving a total of 128 plots, each measuring 5 × 10 = 50 m<sup>2</sup>, arranged in a randomized factorial block design. The original number of plots was 512, as the effects of cultivars and ploughing depth were also studied. Triticale has been grown in a monoculture in the experiment since 1991. The conditions and the lessons learned from the 50 years of the experiment were described in more detail by KÁDÁR et al. (2011).

Alginite was applied on a single occasion at an ameliorative rate of 100 t·ha<sup>-1</sup> in combination with four N doses (0, 50, 100 and 150 kg·ha<sup>-1</sup>·year<sup>-1</sup>). The soil of these plots was acidified and depleted in Ca, Mg, K and P due to the high rate of N fertilization. The plots were halved in autumn 2011 and half the resulting 25 m<sup>2</sup> plots were treated with 100 t·ha<sup>-1</sup> alginite, i.e. 250 kg per plot. The alginite was applied evenly by hand and then mixed into the soil by ploughing and disking. Plots given no alginite served as the control. There were thus 4 N × 4 replications = 16 treatments with alginite, and 4 N × 4 replications = 16 treatments without alginite, giving a total of 32 plots.

The data were statistically evaluated using two-factor multivariate analysis of variance, where the independent variables were the different doses of alginite and nitrogen.

*Characterization of the alginite applied*

The alginite contained 15% moisture, 15% CaCO<sub>3</sub> and 4.6% organic matter. Total-N was 0.15%, K<sub>A</sub> 63, AL-K<sub>2</sub>O 386 and AL-P<sub>2</sub>O<sub>5</sub> 216 mg·kg<sup>-1</sup>. The estimated C/N ratio was about 180. An ameliorative dose of 100 t·ha<sup>-1</sup> alginite was applied on a single occasion in order to study its effect on the physical and water management characteristics of the soil. Table 2 shows the aqua regia-soluble “total” and NH<sub>4</sub>-acetate+EDTA-soluble “mobile” element contents of the alginite, the proportion of the mobile fraction (%) compared to the “total” and the soil load represented by the 100 t·ha<sup>-1</sup> dose.

The alginite contained about 5% Ca, 3.6% Al, 2.9% Fe, 1.9% Mg, 0.82% K, 0.15% P and 0.12% S. The aqua regia-soluble Ni content exceeded the 50 mg·kg<sup>-1</sup> DM limit value.

*Table 2*  
Aqua regia-soluble “total” and NH<sub>4</sub>-acetate + EDTA-soluble “mobile” element contents (mg·kg<sup>-1</sup>) of the alginite and the soil load represented by the 100 t·ha<sup>-1</sup> dose (Ny rlugos long-term field experiment, Ny rs g region, 2011)

Element	Aqua regia-soluble	NH <sub>4</sub> -acetate + EDTA-soluble	Mobile % of the total	Soil load*
Ca	49 942	43 965	88	4 245
Al	36 026	68	<1	3 062
Fe	28 501	934	3	2 423
Mg	19 188	6 969	36	1 631
K	8 166	466	6	694
P	1 501	35	2	128
S	1 237	703	57	105
Mn	587	411	70	50
Na	454	230	51	39
Sr	419	322	77	36
Ba	281	84	30	24
Ni	75.0	14.50	19	6.4
Zn	65.8	5.22	8	5.6
Cr	63.9	0.42	<1	5.4
B	26.8	0.34	1	2.3
Cu	19.2	7.04	37	1.6
Co	15.9	2.80	18	1.4
Pb	9.75	3.92	40	0.85
As	8.84	0.44	5	0.76
Sn	2.84	0.14	5	0.25
Mo	1.86	0.06	3	0.17
Se	1.02	<0.12	-	0.08
Cd	0.12	0.11	92	0.01

*Note:* \*Soil load represented by 100 t·ha<sup>-1</sup> alginite based on the aqua regia element content

In terms of chemical solubility (which is not linked directly to plant availability), the 70–92% mobile fraction ratio of Cd, Ca, Sr and Mn, in descending order, was conspicuous. These were followed by S, Na, Pb, Cu, Mg and Ba with 30–57% mobile fraction ratios. The mobile fractions of Ni and Co only amounted to 18–19%, while those of the other elements remained below 10%. The mobile fraction was about 1% or less in the case of Al, Cr and B, which are incorporated into the crystal lattices (Table 2).

With the  $100 \text{ t} \cdot \text{ha}^{-1}$  dose the ploughed soil layer was loaded with 4.2 t Ca, 3.1 t Al, 2.4 t Fe, 1.6 t Mg, 694 kg K, 128 kg P and 105 kg S per hectare. The total Ni, Zn and Cr load was about  $5\text{--}6 \text{ kg} \cdot \text{ha}^{-1}$  and that of B, Cu and Co  $1\text{--}2 \text{ kg} \cdot \text{ha}^{-1}$ , while the amount of the remaining microelements could only be expressed in decagrams. The quantity of Hg was below the detection limit.

Since alginit is rich in Ca and Mg and relatively rich in K, P and S, it can replace liming materials and, to a lesser extent, K, P and S fertilizers. However, it cannot serve as a N source, so proper N fertilization is essential for a lasting and positive effect.

#### *Plant and soil sampling*

Plant samples were taken each year at the ripening stage from the aboveground plant material on an area of  $1 \text{ m}^2$  from the centre of each plot to avoid the border effect (net plots). The samples were threshed, the grain/straw/husk weights were measured ( $n = 32$ ) and the plant material was milled for laboratory analysis. Soil samples were taken from the ploughed layer after disk-harrowing on 20 July 2012, mixing the samples of 20 drills per plot (representative average sample,  $n = 32$ ) to determine the basic properties and elemental composition of the soil. For soil physical testing (field capacity and effective water) two cylinders were placed in the ploughed layer on the control plots and three on the alginit-treated plots (the larger number of cylinders being required due to soil heterogeneity). There were thus 4 treatments  $\times$  2 cylinders  $\times$  2 replications = 16 samples in the control and 4 treatments  $\times$  3 cylinders  $\times$  2 replications = 24 samples in the alginit treatment, giving a total of 40 tests on undisturbed soil samples. It is planned to perform plant and soil analysis every five years.

#### *Chemical analyses*

Laboratory analyses were conducted in the Institute for Soil Science and Agricultural Chemistry, AKT HAS, using the following methods:

*Plant samples:* air-dry material weighing 0.5 g was treated with  $5 \text{ cm}^3 \text{ cc. HNO}_3$  +  $1 \text{ cm}^3 \text{ cc. H}_2\text{O}_2$ , and then digested for 15 min in a microwave oven. Element concentrations were measured in an ICP detector.

*Soil and alginit samples:* The LAKANEN and ERVIÖ (1971) method was used to analyse the soluble element content. The aqua regia-soluble “total” element content was measured using  $\text{HCl} + 65\% \text{ HNO}_3 + 30\% \text{ H}_2\text{O}_2$ .

Element concentrations were measured in an ICP detector. Tests on the pH,  $y_1$ ,  $\text{CaCO}_3$ , humus, water holding capacity, total salt and total bases were performed according to BARANYAI et al. (1987). Exchangeable cations and T-value were measured with 2.5 g soil by adding 30 cm<sup>3</sup> 1 mol/L  $\text{BaCl}_2$  + trietanol-amin (TEA) shaking solution (J   et al., 1976). After three hours shaking, the elements were measured with an ICP device according to the Hungarian Standards MSZ 08-0214-1:1978 and MSZ 08-0214-2:1978 and BASCOMB (1964). The S-value was calculated as a sum of Ca, Mg, K and Na exchangeable cations. The difference T–S indicates the number of adsorption sites not bound by bases, expressed in me/100 g soil. V% refers to base saturation, indicating the percentage of possible adsorption sites fixed by 1- and 2-valence base cations ( $V = S \cdot 100/T$ ). Thus, V% is saturation expressed as a % of the T-value. Its inverse (reciprocal) value may also be used to indicate the % unsaturation of T ( $U = 100 - V$ ).

#### *Physical soil analysis*

The water capacity and field capacity were characterized as two points on the pF curve. The pF = 0 point, corresponding to total water capacity, was determined from the water saturation of the undisturbed soil columns. Saturation and field capacity water contents were determined on the undisturbed soil cores according to BUZ  S (1993). Moisture content of the collected soil samples were determined by oven-drying (BUZ  S, 1993).

#### *Precipitation*

Monthly and yearly sums of precipitation and the 50-year mean are shown in Table 3.

*Table 3*

Monthly and yearly sums of precipitation between 2011 and 2014, and the 50-year mean, mm (Ny rlugos long-term field experiment, Ny rs g region)

Months	2011	2012	2013	2014	50-year mean
January	33	26	28	32	27
February	11	11	46	28	29
March	41	1	132	15	30
April	19	32	47	24	41
May	34	85	82	79	59
June	42	53	29	27	65
July	133	53	34	122	65
August	34	8	16	57	50
September	28	19	22	33	46
October	29	30	45	65	37
November	1	28	27	18	42
December	50	55	3	35	41
Yearly sums	454	401	511	535	534

The data showed that during the nine-month growing season of triticale only 288 mm of rain fell in the first year, between October 2011 and June 2012, which did not allow the formation of high crop yields in 2012.

The year 2013 was extremely unfavourable. In the spring months of March, April and May the rain was unusually heavy and this period was accompanied by low temperature. The growth of triticale was retarded, and the stand thinned and became infested with weeds. The weather was extremely hot and dry in June and July, corresponding to the generative phase from flowering till ripening, which determines the crop yield. The seed could not develop, so alginite was unable to exert its yield-increasing effect because of the water shortage.

2014 was favourable, due to the abundant rainfall in May. The further rainfall in June, however, was mostly favourable for the development of straw and weeds.

## Results and discussion

### *Effect of N x alginite treatments on some physical parameters of the soil*

The physical soil tests carried out in 2012 showed that neither N fertilization nor alginite treatment had a significant effect on the total porosity of the soil. The total pore volume was 47.5%, so the volume of the solid phase of the soil was 52.5%. Field capacity, i.e. the amount of water stored in the capillary pores, increased from 21–28% of the control to 28–34% (with an increase in the mean from 26% to 31%). This difference, though far from negligible, was not significant, but may have contributed to the positive yield-increasing effect of the dry years.

The soil moisture on 26 September 2012 averaged 5.8% in the control and 7.2% in the alginite treatment, equivalent to an increment of 23%. This could be attributed to the organic and mineral colloids added to the soil with alginite, which is also supported by the significant increase in the saturation percentage ( $K_A$  according to Arany) from 30.2 to 31.6 on average, as a result of the alginite treatment.

### *Effect of N x alginite treatments on some chemical parameters of the soil*

The results of the 2012 soil analysis also showed that excessive N fertilization reduced the pH, so that the soil became extremely acidified over the past half-century. At the same time the cation exchange capacity (CEC or T-value) decreased, as did the quantity of bases, or S-value. In the alginite treatment, the average pH( $H_2O$ ) increased from 5.20 to 6.66 and the pH(KCl) value from 3.87 to 6.16. The acidic sandy soil became practically neutral (Table 4).

The electrical conductivity (EC) tripled, while the CEC and S-value also nearly tripled. EC increased from 21 to 67  $mS \cdot cm^{-1}$ , while  $K_A$  value (saturation percentage) rose from 30.2 to 31.6 in response to alginite treatment. The base saturation of the soil increased from 53 to 74%.



*Table 4*  
Effect of N and alginit treatments on some soil parameters in the ploughed layer, 2012

N rate	pH	pH	Hydrolytic	CEC	S-value	Base
kg·ha <sup>-1</sup> ·yr <sup>-1</sup>	(H <sub>2</sub> O)	(KCl)	acidity (y <sub>1</sub> )	me/100 g		saturation
						%
<i>Without alginit (control)</i>						
0	5.69	4.17	7.5	2.0	1.1	54
50	5.22	3.88	9.3	2.1	1.1	52
100	5.00	3.77	12.4	1.8	1.0	54
150	4.89	3.67	12.3	1.5	0.8	51
<i>Alginit, 100 t·ha<sup>-1</sup></i>						
0	6.75	6.25	5.1	3.4	2.5	74
50	6.76	6.26	5.3	4.5	3.5	77
100	6.67	6.23	6.6	3.5	2.6	74
150	6.49	5.92	7.3	2.9	2.0	70
LSD <sub>5%</sub>	0.25	0.36	2.8	1.2	0.7	12
<i>Means of N treatments</i>						
Control	5.20	3.87	10.4	1.3	1.0	53
Alginit	6.66	6.16	6.1	3.6	2.6	74
LSD <sub>5%</sub>	0.13	0.18	1.4	0.6	0.4	6

*Table 5*  
Effect of N and alginit on the proportion of exchangeable cations in the ploughed layer, 2012

N rate	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Al <sup>3+</sup>	Fe <sup>3+</sup>	K <sup>+</sup>	Total
kg·ha <sup>-1</sup> ·yr <sup>-1</sup>	% of S-value					
<i>Control</i>						
0	61	12	18	6	3	100
50	55	14	17	8	6	100
100	40	12	21	15	2	100
150	35	12	24	22	7	100
<i>Alginit, 100 t·ha<sup>-1</sup></i>						
0	82	13	2	2	1	100
50	78	14	1	5	2	100
100	80	14	2	3	1	100
150	78	15	3	3	1	100
LSD <sub>5%</sub>	24	6	4	6	4	
<i>Means of N treatments</i>						
Control	48	13	20	13	5	100
Alginit	80	14	2	3	1	100
LSD <sub>5%</sub>	12	3	2	3	2	
F-value	***	NA	***	***	***	

Note: F-value: \*95, \*\*99, \*\*\*99.9% interval of significance; NA: not available

A huge change was also indicated by the alteration in the proportion of exchangeable cations. In the  $150 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$  N treatment, the ratio of  $\text{Ca}^{2+}$  dropped to 35%, while the rate of toxic  $\text{Al}^{3+}$  and  $\text{Fe}^{2+}$  increased. With the application of alginit, the ratio of  $\text{Ca}^{2+}$  rose to 80%, similarly to that in neutral soils, while the rate of toxic Al and Fe ions dropped to a tenth and a quarter, respectively. Therefore, the application of alginit at a dose of  $100 \text{ t} \cdot \text{ha}^{-1}$  may result in the amelioration and chemical modification of acidic sandy soils (Table 5).

*Effect of N x alginit treatments on the  $\text{NH}_4$ -acetate+EDTA soluble element content of the soil in the ploughed layer*

The  $\text{NH}_4$ -acetate + EDTA-soluble element content is an important characteristic in agronomic and environmental studies. It refers to the mobility and potential plant uptake of the element, as well as to the absence or abundance of a certain element.

The data in Table 6, in agreement with those in Tables 4 and 5, reflect the impact of large-scale, long-term N fertilization on the loss/excretion of Ca and Mg in the topsoil, and on the harmful accumulation of Fe and Al. In terms of N treatment means, the application of alginit (which enriched the topsoil with approx.  $5 \text{ t} \cdot \text{ha}^{-1}$  elemental Ca) increased the soluble Ca content nearly 5-fold. The treated soil was also enriched in soluble K, Mg and P. The solubility of undesirable elements decreased slightly.

It can be observed that parallel with the high N load and acidification, the most important micro-nutrients in the soil (e.g. Mn, Na, Ba, Sr, Ni) also declined, leading to the impoverishment of the topsoil. After alginit treatment, the concentration of these elements increased. The Sr content increased greatly, by nearly 5-fold.

It is known that Sr is an accompanying element to Ca. Its content in rocks and soils may be about 1% of that of Ca. This Ca:Sr ratio of about 100 is also typical of alginit. Other element concentrations were about Co  $0.25 \text{ mg} \cdot \text{kg}^{-1}$ , Cr  $0.10 \text{ mg} \cdot \text{kg}^{-1}$ , Mo and Cd  $0.01 \text{ mg} \cdot \text{kg}^{-1}$  regardless of the treatment (Table 6).

Table 6

Effect of alginit treatments on the  $\text{NH}_4$ -acetate+EDTA-soluble element contents in the ploughed layer of the soil, averaged over N treatments, 2012 (Brown forest soil, acid sand, Nyírlugos)

N treatment means	Ca	K <sub>2</sub> O	Mg	Ba
	$\text{mg} \cdot \text{kg}^{-1}$			$\mu\text{g} \cdot \text{kg}^{-1}$
Control	154	50	18	3.6
Alginit	730	62	104	4.8
LSD <sub>5%</sub>	116	5	12	0.5
F-value	***	***	***	***

Note: Fe 120, Al 105,  $\text{P}_2\text{O}_5$  101, S 8, Na 7, Zn  $0.6\text{--}0.9 \text{ mg} \cdot \text{kg}^{-1}$ , Co 250, Cr 100, Mo 20, Cd  $10 \mu\text{g} \cdot \text{kg}^{-1}$  regardless of the treatment

*Effect of N x alginit treatments on the yield of triticale*

The development of the crop stand in each plot was evaluated on a 1–5-scale three times during the vegetation period: at tillering, flowering and harvest. It was established that alginit application had a significantly positive effect on triticale development, especially in the 150 kg·ha<sup>-1</sup>·year<sup>-1</sup> N treatment, which had become acidified and infertile during the 50 years of the long-term experiment (Table 7).

Table 7

Effect of N x alginit treatments on the height and air-dry weight of triticale at harvest, 2012

N rate	Height	Grain	By-products	Biomass	By-products/ grain	Grain weight
kg·ha <sup>-1</sup> ·yr <sup>-1</sup>	cm	t·ha <sup>-1</sup>				g·100 <sup>-1</sup> ·yr <sup>-1</sup>
Control						
0	49	1.30	1.57	2.87	1.2	35
50	60	1.86	2.44	4.29	1.3	54
100	62	2.15	2.54	4.70	1.2	65
150	55	1.18	1.74	2.92	1.5	31
Alginit, 100 t·ha <sup>-1</sup>						
0	56	2.01	2.36	4.37	1.2	58
50	63	3.31	3.75	7.06	1.2	81
100	68	3.87	4.52	8.39	1.2	97
150	64	3.38	3.93	7.31	1.2	76
LSD <sub>5%</sub>	8	0.72	0.72	1.40	0.2	18
Means of N treatments						
Control	57	1.62	2.07	3.69	1.3	46
Alginit	63	3.14	3.64	6.78	1.2	78
LSD <sub>5%</sub>	4	0.36	0.36	0.70	1.0	9
F-value	**	***	***	***	**	***

In the first year following the alginit treatment, no rain fell for a month after the triticale was sown (14<sup>th</sup> October 2011), so emergence was delayed. At this stage, no positive effect of the alginit could be detected.

Maximum plant height and yield were achieved with the 100 kg·ha<sup>-1</sup>·yr<sup>-1</sup> N dose on control plots. The greatest N effects in both the vegetative and reproductive stages (by-products, grain weight per year and 1000-kernel weight) were obtained with this N dose. In the 150 kg·ha<sup>-1</sup>·yr<sup>-1</sup> treatment, where the soil acidified to the greatest extent over the decades, plant height and yield mass decreased significantly. However, the decline in the weight of the by-products (straw + chaff) was less pronounced than for the grain, so the by-products/crop ratio increased and the harvest index deteriorated. With the application of alginit, the average height of the plants significantly increased, the grain yield almost doubled and the aboveground

biomass increased from 3.7 t·ha<sup>-1</sup> to 6.8 t·ha<sup>-1</sup>. The harvest index improved, mainly because of the sharp increase in the g/spike and 1000-grain weight parameters.

Earlier experience showed that both extremely wet and extremely dry years lead to drastic yield reductions. In very wet periods the crop thinned, stalk and root rot diseases and fungi occurred and weeds proliferated. In the hot summer months, water shortage occurs very rapidly on sandy soil and the vegetation may be desiccated and dry out.

In 2013, and to some extent in 2012, both the abundance of rainfall in the vegetative phase and the water deficit/drought in the reproductive phase had a devastating effect. During the growing season weather conditions may have different effects on the formation of different yield elements (plant density at emergence, number of spikes at tillering, and thousand-seed weight during maturation).

Favourable weather may increase the 1 000-seed weight in the generative phase, thus slightly offsetting, for example, the negative effects experienced in the vegetative phase, or vice versa. The negative and positive effects may be additive. The yield develops as the result of interactions between different factors.

As Table 8 shows, in 2013 alginit failed to have a spectacularly positive impact, although the effects were significant. The grain yield remained below 1 t·ha<sup>-1</sup> and the aboveground biomass of triticale ranged from 1.5 to 3.0 t·ha<sup>-1</sup>. The air-dry weed mass was approx. 50% of that of triticale (aboveground parts) at harvesting. It is worth mentioning that no chemical weed control was applied in the experiment.

Table 8  
Effect of N x alginit treatments on the height and air-dry yield of triticale and on the air-dry weed biomass at harvest, 2013

N rate kg·ha <sup>-1</sup> ·yr <sup>-1</sup>	Height cm	Grain t·ha <sup>-1</sup>	By-products t·ha <sup>-1</sup>	Triticale t·ha <sup>-1</sup>	By-products/ grain	Weeds t·ha <sup>-1</sup>
<i>Control</i>						
0	44	0.73	1.47	2.20	2.1	1.1
50	36	0.49	1.25	1.74	2.7	1.0
100	39	0.54	1.34	1.88	2.6	1.0
150	38	0.38	1.10	1.48	3.6	0.9
<i>Alginit, 100 t·ha<sup>-1</sup></i>						
0	47	0.93	1.83	2.76	2.0	1.1
50	43	0.69	1.70	2.38	2.5	1.1
100	50	0.76	1.68	2.43	2.5	1.7
150	49	0.89	2.11	3.00	2.4	1.2
LSD <sub>5%</sub>	5	0.30	0.46	0.73	1.1	0.5
<i>Means of N treatments</i>						
Control	39	0.53	1.29	1.82	2.7	1.0
Alginit	47	0.81	1.83	2.64	2.4	1.3
LSD <sub>5%</sub>	3	0.15	0.23	0.37	0.6	0.3
F-value	***	***	***	***		*

The year 2014 was favourable for the development of triticale. Extremely pronounced N effects prevailed in this wet year.

Alginite treatment dramatically increased the efficiency of N fertilization. Due to the application of both N and alginite, the grain and straw yield of triticale increased 5-fold, reaching  $10.5 \text{ t} \cdot \text{ha}^{-1}$  air-dry biomass on plots treated with  $150 \text{ kg} \cdot (\text{ha} \cdot \text{yr})^{-1}$  N. The air-dry weed mass was increased slightly by alginite treatment, while on the control plots the higher triticale yield resulted from the abundant N supply that suppressed the weeds (Table 9).

Table 9

Effect of N x alginite treatments on the height and air-dry yield of triticale and on the air-dry weed biomass at harvest, 2014 (Brown forest soil, acid sand, Ny rlugos)

N rate	Height	Grain	By-products	Triticale	By-products/ grain	Weeds
kg·ha <sup>-1</sup> ·yr <sup>-1</sup>	cm	t·ha <sup>-1</sup>				t·ha <sup>-1</sup>
Control						
0	40	0.44	0.67	1.10	1.3	1.8
50	51	0.62	1.36	1.97	2.2	1.2
100	54	0.62	1.85	2.47	3.2	1.0
150	62	1.85	3.70	5.55	2.0	0.8
Alginit, 100 t·ha <sup>-1</sup>						
0	43	0.68	1.09	1.77	1.6	2.0
50	62	1.60	3.46	5.05	2.4	1.4
100	61	1.51	2.67	4.18	1.9	2.2
150	72	3.81	6.73	10.54	1.8	1.1
LSD <sub>5%</sub>	10	0.84	1.18	1.84	1.0	0.9
Means of N treatments						
Control	52	0.88	1.89	2.77	2.2	1.2
Alginit	59	1.90	3.49	5.39	1.9	1.7
LSD <sub>5%</sub>	5	0.42	0.60	0.94	0.5	0.5
F-value	**	***	***	***		

#### *Effect of N x alginite treatments on the element contents of straw and grain*

As shown in Table 10, the analysis of element composition in 2012 showed that on the control soil K became concentrated in the straw, while Mg was diluted as the N rates increased (decrease in pH, acidification). The well-known relationship between plant Mn uptake and pH was reflected in the Mn accumulation on acidifying soil. Alginite treatment resulted in increasing Ca and Mg and decreasing Mn concentrations in the straw (liming effect). According to the analysis the effect of  $100 \text{ t} \cdot \text{ha}^{-1}$  alginite corresponded to that of  $15.4 \text{ t} \cdot \text{ha}^{-1}$   $\text{CaCO}_3$ , which is an ameliorating liming

dose. The quantity of S applied was  $124 \text{ kg} \cdot \text{ha}^{-1}$ . The S concentration of the straw rose from 0.07% to 0.12% in response to alginit application.

With the increasing N supply and acidification, the concentrations of Zn, Ba and Co increased, while Mo decreased in the straw. The liming effect of alginit reduced the accumulation of Zn and Ba, and even of Cu, Co and Ni averaged over the N treatments.

Table 10

Effect of alginit treatment on the element content of air-dry triticale straw and grain at harvest in 2012, averaged over N treatments (Brown forest soil, acid sand, Nyírlugos)

STRAW						
N treatment means	K	Ca	Mg	P	S	Mn
	%					$\text{mg} \cdot \text{kg}^{-1}$
Control	0.80	0.18	0.06	0.10	0.07	221
Alginit	0.71	0.23	0.13	0.11	0.12	126
LSD <sub>5%</sub>	0.10	0.04	0.02	0.02	0.02	44
F-value		**	***		***	***
N-treatments means	Zn	Ba	Cu	Ni	Mo	Co
	$\text{mg} \cdot \text{kg}^{-1}$					$\mu\text{g} \cdot \text{kg}^{-1}$
Control	16.6	19.7	5.2	3.0	0.39	164
Alginit	12.6	10.7	4.6	2.1	1.42	103
LSD <sub>5%</sub>	2.2	2.3	0.5	0.7	0.50	37
F-value	**	***	*	*	***	**
GRAIN						
N treatment means	Mg	Mn	Zn	Ba	Mo	Cd
	%	$\text{mg} \cdot \text{kg}^{-1}$			$\mu\text{g} \cdot \text{kg}^{-1}$	
Control	0.11	90	36	2.4	200	27
Alginit	0.14	42	32	0.4	889	63
LSD <sub>5%</sub>	0.02	13	3	0.6	184	8
F-value	***	***	**	***	***	***

Notes: In the straw, values of Al 127, Fe 136, Na 18, Sr 14, B 5  $\text{mg} \cdot \text{kg}^{-1}$ ; Cr 225, Cd 105  $\mu\text{g} \cdot \text{kg}^{-1}$  were recorded on average, independently of the treatment. In the grain the following elements were below the given detection limits: Se 600, As 400, Pb 300, Ni 200, Hg, Cr 100, Co 40  $\mu\text{g} \cdot \text{kg}^{-1}$

Mo is known to become mobile in an alkaline medium, so it is more readily available for plants in the form of molybdenum anions. Therefore, the Mo supply of soils in the Nyírség region can be improved by alginit treatment, which could be beneficial from both the agronomic and physiological/nutritional point of view. It is worth noting that the concentrations of the following elements were independent of the treatment: Al 127, Fe 136, Na 18, Sr 14, B 5  $\text{mg} \cdot \text{kg}^{-1}$ , and Cr 225, Cd 105  $\mu\text{g} \cdot \text{kg}^{-1}$  on average. The following elements were below the given detection limits: Se 0.12; Hg 0.10; As 0.08; Sn 0.05  $\text{mg} \cdot \text{kg}^{-1}$  (Table 10).

The grains are genetically better protected, so the treatment effects were less pronounced. On the control soil the concentrations of the macroelements K, P, S, Mg and Ca did not change substantially with changes in the N supply.

However, Mn accumulation was pronounced, as in the case of the straw. The liming effect of alginite was indicated by the elevated Mg and Ca contents and by the decrease in Mn. The S content of the grain also increased slightly, but not significantly.

On the control soil higher Zn, Fe and Ba contents and lower Mo contents were measured as the N doses increased (acidification). After alginite treatment Cd decreased and the incorporation of Mo rose 4-fold, averaged over the N treatments. The concentrations of the elements As, Co, Cr, Hg, Ni, Pb and Se remained below the detection limit.

### Summary

The effect of alginite on the soil and on triticale was studied over three years, from 2012 to 2014, in a long-term field experiment set up on acidic sandy soil in Nyírlugos 53 years ago. A  $100 \text{ t} \cdot \text{ha}^{-1}$  rate of alginite was applied in autumn 2011 on plots given 0, 50, 100 and  $150 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$  N. The originally  $5 \times 10 = 50 \text{ m}^2$  plots were halved, and the halves without alginite treatment served as controls. The  $4\text{N} + 4\text{N}$  (with alginite) = 8 treatments  $\times$  4 replications = 32 plots. The main results are as follows:

1. Physical soil measurements showed that alginite treatment had no effect on the total porosity or water capacity of the soil. The field capacity increased by 4.4% on average, but this was not significant. The saturation percentage ( $K_A$  according to Arany) rose significantly from 30.2 to 31.6.

2. On alginite-treated plots the pH(KCl) increased from 3.9 to 6.2, CEC from 1.3 to 3.6, EC from 21 to 67 ms/cm and base saturation from 53% to 74%, while the hydrolytic acidity decreased from 10 to 6 after the first year.

3.  $\text{NH}_4$ -acetate + EDTA-soluble Ca increased from 154 to 730,  $\text{K}_2\text{O}$  from 50 to 62, Mg from 18 to 104, Sr from 0.9 to  $4.4 \text{ mg} \cdot \text{kg}^{-1}$  and Ni from 125 to  $330 \text{ } \mu\text{g} \cdot \text{kg}^{-1}$  on the alginite-treated plots.

4. The straw and grain yield of triticale increased in all three years. Alginite treatment generally doubled the yields, especially on plots treated with  $150 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$  N, which became acidified and impoverished in Ca, Mg, K and P.

5. Alginite treatment increased the Mg, Mo and Cd uptake and reduced that of Mn, Zn and Ba by triticale seeds. The Ca, Mg, S and Mo concentrations increased in the straw, while the incorporation of Mn, Zn, Ba, Cu, Ni and Co was inhibited by alginite.

6. Alginite is a suitable mineral for the amelioration of similar acid sands, which may eliminate the acidity caused by excessive N supplies and improve the water holding capacity, colloidal and nutrient status and drought-tolerance, and thus their fertility.

**Keywords:** alginite, soil amendment, fertilizer, field experiment, acid soil

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